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x suppressed to meet the confidentiality requirements of the *Statistics Act*
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Cadmium levels and sources of exposure among Canadian adults

by Rochelle Garner and Patrick Levallois

Abstract

Background: Cadmium is a heavy metal found naturally in the environment that has been associated with negative health outcomes. The present study examines levels of blood cadmium (BCd), urinary cadmium (UCd), and the main sources of cadmium exposure among Canadians aged 20 to 79.

Data and methods: The data are from cycles 1 (2007 to 2009) and 2 (2009 to 2011) of the Canadian Health Measures Survey (CHMS), including measures of BCd and UCd, markers of smoking status (self-reported and second-hand smoke exposure), and self-reported consumption of foods known to be high in cadmium. The relationship between sources of exposure and cadmium levels was examined descriptively. The magnitude of the contribution of different exposure sources was examined in regression models.

Results: Age and smoking status were found to be the greatest contributors to BCd and UCd: older people and current smokers had the highest cadmium levels. Dietary exposure, while significant, was a modest contributor overall, but a more important source of cadmium among never-smokers.

Interpretation: Smoking was the greatest contributor to cadmium levels among Canadians aged 20 to 79. Dietary differences explained a small percentage of variation in cadmium levels.

Keywords: Biomonitoring, Canadian Health Measures Survey, environmental exposure, environmental pollution, heavy metals, nutrition, smoking

Cadmium is a heavy metal found in the environment largely as a result of industrial and agricultural processes, but it can also occur naturally.[1] Cadmium can have negative health consequences, including increased risk of cancer, kidney dysfunction, skeletal damage, and possible cardiovascular effects.[1,2] Non-occupational exposure is generally through cigarette smoking[3] and consumption of foods high in cadmium.[1,4,5]

Owing to a biologic half-life of 10 to 35 years, cadmium accumulates in the body, mainly in the liver and kidneys.[6] The level of cadmium in the blood is a good indicator of recent exposure, and urinary cadmium is indicative of long-term exposure, although overlap is substantial.[7]

This analysis uses data from cycles 1 (2007 to 2009) and 2 (2009 to 2011) of the Canadian Health Measures Survey (CHMS) to examine blood (BCd) and urinary (UCd) cadmium levels among Canadians aged 20 to 79, and associations with sources of exposure.

Methods

Data

The CHMS is an ongoing, biennial survey that collects health information through a household interview and direct physical measures at a mobile examination centre (MEC). The CHMS covers the population aged 3 to 79 (minimum age 6 in cycle 1) in the 10 provinces. It excludes full-time members of the Canadian Forces and residents of reserves and other Aboriginal settlements in the provinces, institutions, and certain remote regions. Together, these exclusions represent less than 4% of the target population.[8,9]

The CHMS had overall response rates of 57.1% in cycle 1 and 55.5% in cycle 2. Among households that provided a roster of members, response rates were much higher at 88.3% and 84.9% for the household and MEC components, respectively, in cycle 1, and 90.5% and 81.7% in cycle 2.[8,9] The analytic sample for the present study was limited to respondents aged 20 to 79 (7,095) excluding pregnant women.

Measures

Biological sample collection and analyses

To obtain nationally representative information on a variety of biomarkers (such as nutrition, chronic and infectious diseases, and environmental exposure), blood and urine were collected from all eligible respondents at the MEC. Blood samples were collected from respondents aged 20 to 79 by a phlebotomist using a standardized venipuncture technique. Respondent-provided urine samples were collected using the first-catch urine in cycle 2, and mid-stream urine in cycle 1. Cycle 2 respondents were asked not to urinate for two hours before their appointment. This may have resulted in a shift in creatinine levels between cycles 1 and 2, which could affect creatinine-adjusted levels of some chemicals.

BCd and UCd were measured by inductively coupled plasma mass spectrometry (ICP-MS), Perkin Elmer Sciex, Elan DRC II. Urine creatinine was measured using the colorimetric Jaffe method. Absorbance was read at 505 nm on a Hitachi 917 chemical analyzer. The level of detection for BCd was 0.045 µg/L in both cycles. The detection level for UCd was 0.09 µg/L for cycle 1 and 0.07 µg/L for cycle 2. Urine samples with creatinine below the level of detection (0.049 µg/L) were excluded from analyses (n = 11).[10] For the remaining samples, observations below

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the level of detection for the particular measure (BCd, UCd or urinary cotinine) were imputed with values at half the level of detection. When the level of detection for a test differed between cycles, the highest was used (UCd, 0.09 µg/L; urinary cotinine, 1.1 µg/L). All values were rounded to two significant digits,[11] and were converted from Système International units to conventional units.

For descriptive analyses, UCd was divided by the respondents' urinary creatinine to yield UCd adjusted for creatinine (µg/g). Thirteen respondents were missing both the BCd and UCd measures.

Smoking

Cigarettes and the smoke they generate contain relatively high levels of cadmium in the particulate phase, ranging from 10 to 250 ng per cigarette.[3] Smoking status was based on self-report and was categorized as never-smoker, former smoker, and current smoker. Self-reported never-smokers (n = 41) and former smokers (n = 147) with urinary cotinine levels greater than 50 ng/mL were re-classified as current smokers.[12,13] An indicator variable was used to identify individuals reporting daily or almost daily exposure to second-hand smoke (SHS) at home, in a private vehicle, at work, or in a public place.

Diet

In 2007, Canadians were estimated to have an average daily dietary intake of 0.22 µg of cadmium per kg of body weight.[5] During the household interview, respondents reported the frequency with which they consumed specific foods and food categories. Based on the literature[14-17] and Health Canada's Total Diet Study,[18] yearly consumption of the following foods was examined as a possible source of cadmium: liver (excluding liverwurst and liver pâté) and/or other organ meats (for example, kidneys, heart, giblets); shellfish (lobster, shrimp, mussels, scallops, oysters, clams, squid, crab and other shellfish); cereals (hot or cold); white or brown breads (including bagels, rolls, pita bread, tortillas); fries and hash brown potatoes; other potatoes (excluding sweet potatoes); green salads; dark leafy greens (spinach, mustard greens or collards, excluding kale); and nuts and seeds (peanuts, walnuts, seeds, or other nuts, excluding nut butters such as peanut butter). Annual consumption values had a minimum of 0, but no prescribed maximum, as individuals could consume items from a particular food category many times a day. A dichotomous variable was included to indicate whether respondents had consumed red meat in the past year.

Shellfish consumption was determined differently in cycle 1 and cycle 2. In cycle 1, shellfish consumption was assessed with one general item during the household interview. In cycle 2, shellfish consumption was assessed during the MEC interview with nine separate items; annual consumption was asked only of respondents who reported consumption of the specific shellfish in the past month. Responses to the nine items were summed for cycle 2 respondents to yield annual consumption. To improve comparability between cycles, consumption less than 12 times a year from cycle 1 was converted to zero consumption (n = 742). In each cycle, about the same percentages of respondents were non-consumers of shellfish (44.6% in cycle 1, 41.0% in cycle 2, chi-square p = 0.30), although the frequency of consumption was greater among cycle 2 consumers (mean 60.1 times a year versus 37.1 times a year in cycle 1, t-test p-value < 0.0001).

Based on earlier studies,[16,17] several other covariates were included in the models. Hemoglobin levels below 120 g/L in women and below 130 g/L in men were used as indicators of anemia.[19] Body mass index (BMI), defined as weight in kilograms divided by height in metres squared, was derived from respondents' measured height and weight. Because parity has been associated with cadmium levels in women,[16,20] the reported number of live births was included in female-specific models: zero (nulliparous), one, two, or three or more. An indicator of CHMS cycle was included to account for other unmeasured differences between cycles.

Statistical analysis

For descriptive analyses, the geometric means of cadmium levels were produced, along with their standard errors. Dietary consumption items were usually categorized as non-consumption (0 times a year), less than weekly (1 to 51 times a year), and at least weekly (52 or more times a year). The exceptions were shellfish, for which the lowest consumption category was fewer than 12 times a year, and cereal and bread, with categories of non-consumption, less than daily (fewer than 365 times a year), and daily (365 or more times a year).

For regression analyses, the outcome variable was the natural logarithm of the BCd or UCd concentration. As recommended by Barr et al.,[21] the urinary creatinine level was included as a covariate in the UCd model; this value was also transformed using the natural logarithm. Dietary consumption measures were centered at their mode values, and divided by 12 so that a unit change in the consumption variables reflected consuming the particular product an additional time per month. Mode values were: 0 for organ meats (63.7% were non-consumers), shellfish (42.6%), and leafy greens (31.5%); 52 for french fries (22.6%), other potatoes (22.6%), and nuts and seeds (15.4%); 104 for salad (16.2%); and 365 for bread (19.8%). The mode value for cereal was 365, but because so few respondents had higher consumption values (0.6%), this variable was centered at its median of 104.

Continuous BMI was centered at 21.75, and age was centered at 45. Both variables were subsequently divided by 5 so that a one-unit change in the covariates related to a 5-unit change in BMI and age.

To assess the impact of the selected predictors on cadmium levels, multivariate models were built in a sequential block-wise fashion, showing the change in model R^2 associated with each block of covariates. Blocks were added in the following order: linear and quadratic effects of age; smoking status (never-smokers as reference) and exposure to SHS; consumption of certain foods; and other factors, including anemia,

BMI, CHMS cycle indicator, and parity (women). Urinary creatinine (ln-transformed) was included in the model for UCd before adding age. Separate models were developed for men and women. Sex-specific models were also run for never-smokers.

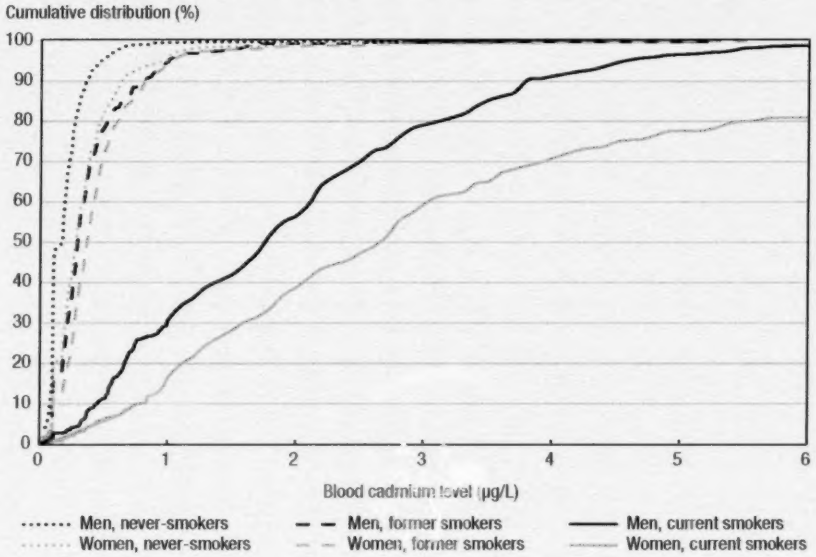
All analyses were conducted in SAS-callable SUDAAN (version 11.0.1) using 24 denominator degrees of freedom. Analyses were weighted using the cycle 1-cycle 2 combined sample weights and bootstrapped to account for the sample design.[11]

Results

The mean age of the 7,082 respondents was 46.3 (SE 0.15) for women and 45.3 (SE 0.18) for men. Nearly a quarter of respondents (23.2%) were current smokers, 28.1% were former smokers, and 48.8% were never-smokers. Close to a quarter (23.6%) were exposed to SHS daily or almost daily.

Cadmium levels were significantly higher in women than men, in older relative to younger people, in former and current smokers relative to never-smokers, and among people exposed to SHS (Table 1). Figure 1 shows the cumulative distribution of BCd levels by sex and smoking status. Figure 2 shows the same distribution for UCd, adjusted for creatinine. Regardless of smoking status, women had higher average cadmium levels than men, a difference that was most pronounced among never-smokers and current smokers.

Figure 1
Cumulative distribution of blood cadmium levels (µg/L), by sex and smoking status, household population aged 20 to 79, Canada excluding territories, 2007 to 2011



Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

Frequent consumption of organ meats was associated with higher cadmium levels; frequent consumption of leafy greens and nuts and seeds was associated with lower cadmium (Table 1). Frequent consumption of cereal, salad,

Table 1
Description of sample and geometric mean (GM) of blood and urinary cadmium levels, by selected characteristics, household population aged 20 to 79, Canada excluding territories, 2007 to 2011

	Sample		Blood cadmium (µg/L)		Urinary cadmium (µg/L)		Urinary cadmium, creatinine adj. (µg/g)	
Characteristic	Number	%	GM	Standard error	GM	Standard error	GM	Standard error
Survey cycle								
1	3,471	44.9	0.41	0.02	0.38*	0.02	0.46*	0.01
2†	3,611	55.1	0.37	0.02	0.44	0.02	0.41	0.02
Sex								
Women	3,764	50.1	0.43*	0.02	0.41	0.01	0.53*	0.01
Men†	3,318	49.9	0.34	0.01	0.41	0.01	0.35	0.01
Age group								
20 to 39	2,433	37.2	0.31*	0.02	0.31*	0.01	0.29*	0.01
40 to 59†	2,465	41.2	0.44	0.02	0.46	0.02	0.50	0.01
60 to 79	2,184	21.6	0.45	0.01	0.52*	0.02	0.66*	0.02
Smoking status								
Never-smoker†	3,369	48.8	0.21	0.01	0.33	0.01	0.35	0.01
Former smoker	2,086	28.1	0.33*	0.02	0.44*	0.02	0.50*	0.02
Current smoker	1,608	23.2	1.64*	0.07	0.59*	0.03	0.58*	0.02
Second-hand smoke exposure								
Daily or almost daily	1,458	23.6	0.66*	0.04	0.50*	0.02	0.46*	0.02
Less than almost daily†	5,623	76.4	0.33	0.01	0.38	0.01	0.42	0.01

Table 1 (concluded)
Description of sample and geometric mean (GM) of blood and urinary cadmium levels, by selected characteristics, household population aged 20 to 79, Canada excluding territories, 2007 to 2011

Characteristic	Sample		Blood cadmium (µg/L)		Urinary cadmium (µg/L)		Urinary cadmium, creatinine adj. (µg/g)	
	Number	%	GM	Standard error	GM	Standard error	GM	Standard error
Diet								
Organ meats								
No consumption†	4,439	63.7	0.36	0.02	0.39	0.01	0.40	0.01
1 to 51 times/year	1,452	20.1	0.42	0.02	0.42	0.02	0.48*	0.02
52 or more times/year	1,191	16.2	0.45*	0.02	0.48*	0.02	0.52*	0.02
Shellfish								
Fewer than 12 times/year†	3,034	42.6	0.40	0.02	0.43	0.02	0.45	0.01
12 to 51 times/year	2,708	37.7	0.36	0.02	0.39*	0.01	0.41*	0.01
52 or more times/year	1,333	19.7	0.40	0.02	0.41	0.02	0.43	0.02
Cereal								
No consumption†	1,005	15.8	0.50	0.03	0.51	0.02	0.52	0.02
1 to 364 times/year	4,390	62.1	0.38*	0.02	0.40*	0.01	0.41*	0.01
365 or more times/year	1,687	22.1	0.34*	0.02	0.37*	0.02	0.45*	0.02
Bread								
No consumption	90	1.6E	0.51*	0.07	F	...	0.56E	0.09
1 to 364 times/year†	2,700	39.0	0.36	0.02	0.40	0.02	0.41	0.01
365 or more times/year	4,291	59.5	0.40*	0.01	0.41	0.01	0.45*	0.01
French fries								
No consumption†	1,031	13.9	0.43	0.02	0.43	0.02	0.55	0.02
1 to 51 times/year	3,155	42.4	0.36*	0.02	0.38	0.01	0.45*	0.01
52 or more times/year	2,895	43.7	0.40	0.02	0.43	0.02	0.39*	0.01
Other potatoes								
No consumption†	360	4.9	0.41	0.03	0.45	0.06	0.50	0.05
1 to 51 times/year	1,501	23.2	0.35	0.02	0.36	0.02	0.40*	0.02
52 or more times/year	5,219	72.0	0.40	0.01	0.42	0.01	0.44	0.01
Salad								
No consumption†	330	4.8	0.49	0.06	0.47	0.04	0.48	0.05
1 to 51 times/year	712	10.4	0.48	0.03	0.49	0.03	0.45	0.02
52 or more times/year	6,036	84.8	0.37*	0.01	0.40*	0.01	0.43	0.01
Leafy greens								
No consumption†	2,264	31.5	0.46	0.02	0.46	0.02	0.45	0.02
1 to 51 times/year	2,449	34.8	0.37*	0.02	0.39*	0.01	0.43	0.01
52 or more times/year	2,365	33.7	0.34*	0.02	0.38*	0.02	0.42	0.02
Nuts and seeds								
No consumption†	857	11.7	0.50	0.04	0.50	0.03	0.49	0.03
1 to 51 times/year	2,318	32.9	0.40*	0.02	0.43*	0.01	0.42*	0.01
52 or more times/year	3,902	55.4	0.36*	0.01	0.38*	0.02	0.43*	0.01
Red meat consumption in past year								
No	252	3.8	0.38*	0.03	0.35*	0.03	0.49	0.04
Yes†	6,830	96.2	0.39*	0.01	0.41	0.01	0.43	0.01
Anaemic (low hemoglobin)								
Yes	431	5.0	0.40*	0.03	0.46	0.04	0.55*	0.02
No†	6,651	95.0	0.39	0.01	0.41	0.01	0.43	0.01
Body mass index category, measured								
Underweight	99	1.7	0.57E	0.13	0.39E	0.09	0.60*	0.08
Normal weight†	2,437	36.8	0.42	0.02	0.39	0.02	0.44	0.02
Overweight	2,627	36.0	0.37	0.02	0.42	0.02	0.42*	0.01
Obese class I	2,627	15.8	0.38	0.02	0.42	0.02	0.42*	0.02
Obese classes II and III	715	9.7	0.34*	0.01	0.44	0.03	0.43*	0.02
Parity (women)								
Nulliparous†	807	28.4	0.34	0.02	0.32	0.02	0.38	0.02
One	682	18.6	0.50*	0.06	0.42*	0.02	0.56*	0.03
Two	1,303	30.9	0.43*	0.03	0.42*	0.02	0.57*	0.02
Three or more	939	22.1	0.52*	0.05	0.52*	0.03	0.70*	0.04

† reference category
* significantly different from reference category ($p < 0.05$)
... not applicable
E use with caution
F too unreliable to be published
Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

leafy greens, and nuts and seeds was associated with lower BCd. Frequent consumption of bread, french fries and hash browns, and nuts and seeds was associated with lower creatinine-adjusted UCd. Consumption of red meat was not related to cadmium levels (BCd or creatinine-adjusted UCd). Anaemia (low hemoglobin) was significantly associated with higher creatinine-adjusted UCd, but not with BCd. BMI was significantly related to cadmium levels, as was parity among women.

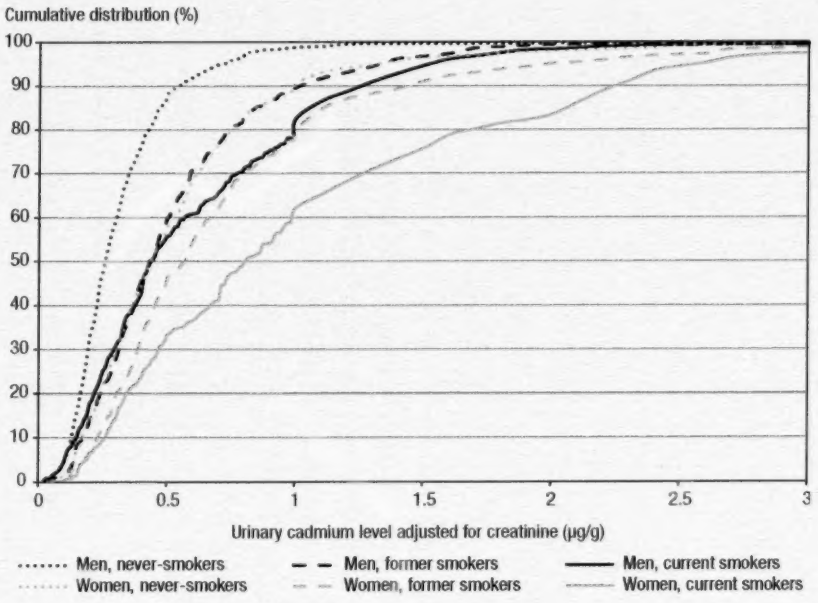
Multivariate results

The combined association of these characteristics with cadmium levels was examined in multivariate regression models. Smoking status and SHS exposure explained the greatest amount of variation in BCd levels (Table 2). Current and former smokers had significantly higher BCd than did never-smokers. Among men who reported daily or near-daily exposure to SHS, BCd was 22% greater than among men exposed less frequently; the relationship was not significant for women ($p = 0.11$).

Age explained the next greatest amount of variation, with older respondents having higher BCd than did younger respondents. As a block, dietary factors explained about 1% of the variation in BCd levels. BCd was lower among people with frequent cereal consumption. Among women, frequent shellfish consumption was positively associated with BCd, while frequent consumption of potatoes other than french fries was negatively associated with BCd; these were not significant for men ($p = 0.07$ and $p = 0.08$, respectively). For both sexes, higher BMI was related to lower BCd. Anaemia was associated with higher BCd among men, but not among women.

After urinary creatinine, age was the next largest contributor to variations in UCd, followed by smoking status and SHS exposure (Table 3). As with BCd, former and current smokers had higher UCd than did never-smokers, although the impact of smoking status (compared with never-smokers) on UCd was less than on BCd. As well, men and women who reported daily or near-daily SHS exposure had higher UCd than did those exposed less frequently. Diet generally explained 1% or less of variation in UCd. Men who were anaemic had significantly higher UCd than those who were not. Parity was significant for women—those who had given birth had higher UCd than nulliparous women.

Figure 2
Cumulative distribution of urinary cadmium levels adjusted for creatinine (µg/g), by sex and smoking status, household population aged 20 to 79, Canada excluding territories, 2007 to 2011



Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

Never-smokers

When analyses were limited to never-smokers, the explanatory impact of diet on cadmium levels increased, and the strong association with age persisted. Cadmium levels were significantly higher among never-smokers who did not consume red meat (except for UCd in women). Among men, frequent organ meat consumption was associated with higher BCd, and frequent bread and cereal consumption was associated with lower BCd (Table 2). Among women, frequent consumption of potatoes (excluding french fries and hash browns) was associated with lower BCd (Table 2) and UCd (Table 3). Higher BMI was negatively associated with BCd and UCd among never-smokers. UCd was 30% to 50% higher among female never-smokers who had children, compared with those who were nulliparous (Table 3).

Discussion

The present study found that cadmium levels were strongly associated with smoking, while the impact of diet was modest to small. Consistent with the literature,[7,16,22] current and former smokers had higher BCd and UCd than did never-smokers. Exposure to SHS was associated with significantly higher UCd among both sexes, and with higher BCd among men overall. However, SHS exposure was not associated with cadmium levels among never-smokers, which is similar to other research.[22] In the present study, exposure to SHS was less frequent among never-smokers than among current smokers (15% versus 52%, $p < 0.0001$), which may explain why it was significant overall but not

Table 2
Regression model estimates of association between selected characteristics and blood cadmium levels, all respondents and never-smokers only, by sex, household population aged 20 to 79, Canada excluding territories, 2007 to 2011

	All respondents						Never-smokers					
	Women (n = 3,651)			Men (n = 3,268)			Women (n = 1,899)			Men (n = 1,394)		
		95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval	
Characteristic	e^{Beta}	from	to	e^{Beta}	from	to	e^{Beta}	from	to	e^{Beta}	from	to
Intercept	0.29	0.24	0.35	0.21	0.18	0.24	0.26	0.21	0.32	0.19	0.16	0.22
Block 1: Age	change in R^2 = 0.0324			change in R^2 = 0.0268			change in R^2 = 0.0571			change in R^2 = 0.0941		
Age (centered at 45, 1 unit = 5 years)												
Linear	1.09*	1.06	1.12	1.08*	1.07	1.10	1.07*	1.04	1.09	1.08*	1.06	1.10
Quadratic	0.99*	0.99	1.00	1.00	0.99	1.00						
Block 2: Smoking	change in R^2 = 0.5118			change in R^2 = 0.5842			change in R^2 = 0.0019			change in R^2 = 0.0007		
Smoking status												
Never-smokers†	...	...	...	...	...	...	...	...	...	...	...	...
Former smokers	1.23*	1.03	1.47	1.64*	1.50	1.79	...	...	...	...	...	...
Current smoker	7.05*	6.07	8.18	8.12*	6.93	9.52	...	...	...	...	...	...
Daily/Almost daily second-hand smoke exposure												
No†	...	...	...	...	...	...	...	...	...	...	...	...
Yes	1.10	0.98	1.23	1.22*	1.11	1.35	0.97	0.84	1.12	0.99	0.83	1.17
Block 3: Diet (1 unit = 12 times/year)	change in R^2 = 0.0136			change in R^2 = 0.0091			change in R^2 = 0.0595			change in R^2 = 0.0585		
Organ meat, centered at 0	1.008	0.996	1.021	0.999	0.949	1.051	1.014	0.984	1.045	1.049*	1.009	1.092
Shellfish, centered at 0	1.022*	1.006	1.038	1.007	0.999	1.016	1.020	1.000	1.040	1.004	0.991	1.017
Cereal, centered at 104	0.996*	0.993	0.999	0.996*	0.992	1.000	0.996	0.991	1.000	0.994*	0.990	0.998
Bread, centered at 365	0.999	0.997	1.002	0.998	0.995	1.000	0.998	0.994	1.001	0.996*	0.993	1.000
French fries, centered at 52	1.001	0.994	1.008	0.994	0.984	1.005	0.999	0.973	1.026	0.997	0.980	1.014
Other potatoes, centered at 52	0.993*	0.988	0.997	1.004	0.999	1.008	0.988*	0.981	0.995	1.004	0.996	1.013
Salad, centered at 104	1.000	0.996	1.003	0.996	0.993	1.000	1.000	0.995	1.004	0.999	0.995	1.003
Other leafy greens, centered at 0	0.994	0.987	1.001	0.998	0.990	1.005	0.992	0.980	1.004	1.003	0.995	1.011
Nuts and seeds, centered at 52	1.001	0.997	1.005	0.997*	0.994	1.000	1.003	0.999	1.008	0.998	0.994	1.002
Red meat consumption in past year												
No	1.27	0.97	1.66	1.28	0.99	1.65	1.38*	1.00	1.91	1.42*	1.04	1.95
Yes†	...	...	...	...	...	...	...	...	...	...	...	...
Block 4: Other	change in R^2 = 0.0089			change in R^2 = 0.0099			change in R^2 = 0.0377			change in R^2 = 0.0297		
Anaemic (low hemoglobin)												
Yes	1.12	0.94	1.34	1.22*	1.07	1.39	1.29*	1.02	1.62	1.31*	1.06	1.61
No†	...	...	...	...	...	...	...	...	...	...	...	...
Body mass index, measured (centred at 21.75, 1 unit = 5 BMI points)	0.94*	0.91	0.97	0.89*	0.86	0.93	0.92*	0.87	0.97	0.88*	0.83	0.94
Parity (women)												
Nulliparous†	...	...	...	...	...	...	...	...	...	...	...	...
One	1.15	0.93	1.40	...	...	...	1.27	0.99	1.62	...	...	...
Two	1.02	0.87	1.20	...	...	...	1.02	0.83	1.25	...	...	...
Three or more	1.13	0.99	1.30	...	...	...	1.21*	1.05	1.40	...	...	...
CHMS cycle												
1†	...	...	...	...	...	...	...	...	...	...	...	...
2	0.94	0.82	1.08	0.90	0.81	1.00	1.02	0.85	1.23	0.98	0.87	1.11
Total R^2	R^2 = 0.5667			R^2 = 0.6300			R^2 = 0.1561			R^2 = 0.1831		

† reference category
* effect is statistically significant ($p < 0.05$)
... not applicable
Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

among never-smokers. The association with SHS may also depend on time since exposure.

Although consumption of certain foods was associated with cadmium levels, the variation explained by diet tended to be small in multivariate models. The explanatory contribution of diet increased dramatically when the analysis was limited to never-smokers, thereby eliminating the potential contribution of tobacco smoke. Some earlier research found consumption of shellfish and organ meats to be related to higher cadmium levels, but in the present study, these associations were not consistent in all models.[1,14,15] Moreover, other studies also failed to find an association between

Table 3
Regression model estimates of association between selected characteristics and urinary cadmium levels, all respondents and never-smokers only, by sex, household population aged 20 to 79, Canada excluding territories, 2007 to 2011

	Total						Never-smokers					
	Women (n = 3,666)			Men (n = 3,259)			Women (n = 1,903)			Men (n = 1,391)		
		95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval	
Characteristic	e^{Beta}	from	to	e^{Beta}	from	to	e^{Beta}	from	to	e^{Beta}	from	to
Intercept	0.48	0.43	0.55	0.35	0.31	0.39	0.41	0.34	0.48	0.29	0.27	0.32
Block 1: Adjustment	change in R^2 = 0.4769			change in R^2 = 0.4644			change in R^2 = 0.5356			change in R^2 = 0.5970		
Urinary creatinine, natural log (µg/L)	1.01*	2.68	2.92	2.78*	2.63	2.93	1.01*	2.67	3.01	2.69*	2.52	2.87
Block 2: Age	change in R^2 = 0.1201			change in R^2 = 0.1169			change in R^2 = 0.0743			change in R^2 = 0.0300		
Age (centered at 45, 1 unit = 5 years)												
Linear	1.14*	1.12	1.16	1.12*	1.10	1.14	1.09*	1.07	1.11	1.06*	1.05	1.08
Quadratic	0.99*	0.99	0.99	0.99*	0.99	1.00						
Block 3: Smoking	change in R^2 = 0.0525			change in R^2 = 0.0477			change in R^2 = 0.0000			change in R^2 = 0.0003		
Smoking status												
Never-smoker†	...	...	...	...	...	...	...	...	...	...	...	...
Former smoker	1.17*	1.07	1.28	1.30*	1.20	1.41	...	...	...	...	...	...
Current smoker	1.79*	1.63	1.97	1.57*	1.37	1.80	...	...	...	...	...	...
Daily/Almost daily second-hand smoke exposure												
No†	...	...	...	...	...	...	...	...	...	...	...	...
Yes	1.11*	1.01	1.21	1.18*	1.08	1.28	1.05	0.90	1.23	1.08	0.94	1.25
Block 4: Diet (1 unit = 12 times/year)	change in R^2 = 0.0050			change in R^2 = 0.0087			change in R^2 = 0.0131			change in R^2 = 0.0121		
Organ meat, centered at 0	1.018	0.996	1.041	1.006	0.976	1.038	1.014	0.981	1.048	1.025	0.996	1.055
Shellfish, centered at 0	1.010	0.998	1.021	1.006	0.997	1.015	1.010	0.993	1.026	1.000	0.988	1.013
Cereal, centered at 104	0.999	0.997	1.001	0.999	0.995	1.002	0.998	0.995	1.001	0.999	0.996	1.002
Bread, centered at 365	1.000	0.999	1.002	0.999	0.998	1.001	1.001	0.999	1.002	0.999	0.997	1.002
French fries, centered at 52	1.000	0.994	1.007	0.991	0.982	1.001	0.998	0.976	1.021	0.993	0.983	1.003
Other potatoes, centered at 52	0.995*	0.991	0.999	1.001	0.997	1.006	0.989*	0.981	0.997	1.000	0.993	1.007
Salad, centered at 104	0.999	0.996	1.002	0.998	0.994	1.002	0.997	0.994	1.001	1.000	0.995	1.004
Other leafy greens, centered at 0	0.996	0.991	1.001	0.996	0.992	1.001	1.001	0.996	1.006	1.003	0.997	1.008
Nuts and seeds, centered at 52	1.000	0.997	1.003	0.998	0.995	1.000	1.003	0.999	1.007	0.999	0.996	1.002
Any red meat in past year												
No	1.17	0.99	1.38	1.34*	1.09	1.64	1.10	0.90	1.34	1.36*	1.03	1.81
Yes†	...	...	...	...	...	...	...	...	...	...	...	...
Block 5: Other	change in R^2 = 0.0141			change in R^2 = 0.0103			change in R^2 = 0.0358			change in R^2 = 0.0080		
Anaemic (low hemoglobin)												
Yes	1.08	0.97	1.20	1.24*	1.13	1.37	1.05*	0.85	1.29	1.32*	1.13	1.55
No†	...	...	...	...	...	...	...	...	...	...	...	...
Body mass index, measured (centred at 21.75, 1 unit = 5 BMI points)	0.92*	0.89	0.96	0.92*	0.88	0.97	0.90*	0.85	0.94	0.93*	0.88	0.98
Parity (women)												
Nulliparous†	...	...	...	...	...	...	...	...	...	...	...	...
One	1.19*	1.04	1.37	...	...	...	1.45*	1.19	1.78	...	...	...
Two	1.10	1.00	1.21	...	...	...	1.33*	1.17	1.50	...	...	...
Three or more	1.21*	1.06	1.38	...	...	...	1.49*	1.25	1.78	...	...	...
CHMS cycle												
1†	...	...	...	...	...	...	...	...	...	...	...	...
2	0.93	0.84	1.02	0.88*	0.79	0.97	0.89	0.78	1.02	0.95	0.84	1.07
Total R^2	R^2 = 0.6687			R^2 = 0.6481			R^2 = 0.6588			R^2 = 0.6473		

† reference category
* effect is statistically significant ($p < 0.05$)
... not applicable
Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

shellfish consumption and cadmium levels when controlling for other factors.[14-16,23]

Consumption of other high-cadmium foods, such as potatoes, nuts and seeds, and leafy greens, was either not significant, or frequent consumption was associated with lower cadmium levels. Such findings illustrate the complex

interplay between dietary composition and the absorption of metals and other toxins. For example, levels of iron, fiber and zinc may affect the degree to which cadmium is absorbed by the body.[24-26]

Adjusting for urinary creatinine in the UCd models explained the greatest proportion of variation in cadmium levels. Creatinine adjustment corrects for inter-sample differences in the concentration of urine, which can affect levels of other chemicals. Cadmium and creatinine levels in urine are highly correlated (Pearson correlation rho=0.43, $p < 0.0001$ in the present study). Furthermore, urinary creatinine is associated with other covariates, such as age and BMI.[27] Therefore, some of the variance explained by urinary creatinine could also be attributed to these factors.

When urinary creatinine was taken into account, the remaining covariates explained about 10% of the variation in UCd. Given that UCd is considered to be an indicator of long-term exposure,[7] current behaviours (for example, diet, smoking) reported to a cross-sectional survey are limited in their ability to explain differences in exposure levels. Accounting for longer-term behaviour and exposure may explain more of the differences in UCd at the population level.

Consistent with other reports,[7,22] women in the present study had higher cadmium levels than men. Choudhury et al. have proposed that, because of their lower iron stores, women absorb a larger proportion of ingested cadmium.[28] An association between iron stores and cadmium levels has been demonstrated by others.[24,29] Such an explanation is consistent with this study's findings that non-consumption of iron-rich red meat was related to higher cadmium levels, and that frequent consumption of cereals and breads, which are often fortified with iron, was related to lower cadmium levels. Anaemia (low hemoglobin) was significant only among men (although a positive association with BCd emerged for never-smoking women). When whole blood ferritin levels were used as a measure of iron store rather than hemoglobin levels (cycle 2 respondents only), low (less than 30 µg/L) ferritin was significantly predictive of higher BCd for women (beta = 0.20, $p = 0.004$) and men (beta = 0.44, $p = 0.002$), but was not associated with UCd for either sex.

Factors beyond smoking and diet were also related to cadmium levels. BCd and UCd were lower among those with higher BMI, overall and when analyses were limited to never-smokers. Some research has found higher BMI to be associated with lower cadmium in blood[23] and urine,[30] although others failed to find an association.[14] Consistent with previous analyses,[16,23] the current study found that women with more children had significantly higher cadmium levels, particularly UCd, compared with nulliparous women. Åkesson et al. surmised that decreased iron stores among parous women explained their higher cadmium levels.[20]

Limitations

This analysis has a number of limitations. Because the CHMS is cross-sectional, the present study can describe associations between cadmium levels and other factors, but it is not possible to assign causality. In addition, although geographic variations in exposure may explain some of the differences in cadmium levels,[17] the CHMS was designed to produce only national estimates. Further, differences between cycles 1 and 2 in the way data were collected, particularly urine samples and shellfish consumption information, may affect results. As well, it was not always possible to isolate the consumption of specific foods in a category, and foods such as sweet potatoes and tofu, found to be associated with cadmium levels in other studies,[14] were not included in the CHMS. Consumption frequency was based on recollection and extrapolated to yearly values, which may not reflect actual consumption. Lastly, the response rate of the combined sample from cycles 1 and 2 was 53.5%. This largely reflects a low response rate among households initially contacted for participation; households that agreed to provide a household roster had high response rates (more than 80%) to the interview and MEC components of the survey. It is not known if households that initially declined to participate differed in important ways from participating households.

What is already known on this subject?

- Cadmium exposure is related to health conditions, such as cancer, kidney disease, and hypertension.
- Non-occupational exposure is generally through exposure to cigarette smoke and consumption of foods high in cadmium.

What does this study add?

- Combining the first two cycles of the Canadian Health Measures Survey allows for a more detailed examination of cadmium levels and sources of exposure among Canadians than has been possible before now.
- Diet is an important source of cadmium exposure only among never-smokers.
- Men and women differ in the extent to which sources of exposure are related to overall blood and urinary cadmium levels.

Conclusion

According to the present study, smoking behaviour was found to be the greatest contributor to cadmium levels among Canadians aged 20 to 79, with modest or small contributions from diet. However, among non-smokers, diet may be a significant source of cadmium. ■

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